Dual-task tests: differences and changes in motor function in persons with varying levels of cognitive impairment – a systematic review.

Abstract

Background – Dementia is one of the key public challenges of this century with the number of persons with dementia worldwide projected to reach 115 million by 2050. Emerging research on the mirroring of changes in cognitive capacity in motor function may enable early detection of dementia. The goal of this review was to assess the evidence about differences in motor parameters under dual-task conditions among persons with varying levels of cognitive impairment.

Methods – The author conducted a systematic review of peer-reviewed articles published between January 1970 and October 2017 that were found by querying PubMed. To be included, studies needed to provide quantitative assessments of cognitive and motor functions, use dual-task tests and be performed by at least two groups of individuals with distinct levels of cognitive ability.

Results – After screening 221 retrieved abstracts, the author fully-reviewed 24 articles, of which 12 are included in this review. Gait speed during dual-task tests and gait speed dual-task cost differ between healthy individuals and persons with cognitive impairment. Such differences do not exist between patients with mild cognitive impairment and Alzheimer's disease. More studies are needed to make

meaningful conclusions about other motor parameters and performance on the "Timed Up and Go" test.

Conclusions – Differences and changes in gait speed under dual-task conditions suggest that monitoring of this parameter may be used in dementia screening. Harmonization of results, a stronger focus on ecological validity, and the introduction of novel analytical methods are needed to increase the quality of evidence and ensure its clinical relevance.

Introduction

Burden of problem

Nearly 46 million people worldwide suffered from some form of dementia in 2015, with this number estimated to increase by 6-10 million new cases per year [1, 2]. In the U.S. alone, Alzheimer's disease affected an estimated 5.4 million in 2017 and was the fifth leading cause of death among older Americans [3]. Due to a plethora of physical, behavioral, and psychological symptoms [4], dementia greatly diminishes the quality of life [5]. As the number of persons with dementia is projected to more than double by 2050, reaching 115 million worldwide [2], dementia constitutes one of the major public health challenges of this century.

What is known?

Dementia manifests itself in a wide spectrum of symptoms ranging from memory loss, confusion, and anxiety to difficulties in speaking, problem-solving, and performing activities of daily living [6]. Furthermore, patients with dementia suffer from motor dysfunctions and are at an increased risk of falling [7 8]. A growing body

of research points to dementia-resultant attention deterioration [9] as a risk factor for falls, linking cognitive impairment with motor function.

Relevant evidence originating from dual-task studies shows that experimentally constrained attentional resources hinder our ability to concurrently perform multiple tasks, e.g., to walk and talk at the same time. In such studies, participants complete at least two types of tests – often, a single-task test and dual-task test - each with a different level of cognitive load (CL). For example, in the first test subjects only walk (single-task test, low CL) while in the second test the same participants walk and say the alphabet backward at the same time (dual-task test, high CL). The difference in the outcome variable – here, walking speed - measured during the single- and dual-task tests is referred to as a dual-task cost (DTC). As higher levels of CL limit attentional resources more than lower levels, the DTC allows us to quantify the impact of attention impairment on the measured outcome. Therefore, dual-task experiments can provide valuable insight into how declining attentional capacity is mirrored in motor function, enabling accurate modeling of this phenomenon.

Why is this review needed?

While emerging research on motor function and dementia is very rich, relatively few studies investigate this relationship in a dual-task paradigm forgoing its benefits. Heterogeneity in study designs, reported measures and implementations as well as relatively simplistic statistical analysis and insufficient focus on test-retest reliability in DT studies further inhibit our ability to compare estimates and

generalize findings. Therefore, a systematic summary of existing high-quality evidence aimed at grouping findings by experimental design and outcome is essential to establishing best practices, harmonizing reported measures, synthesizing results, and guiding future research in this area.

Importance of variable of interests and Implications of results

Given the prevalence of dementia, it is critical to deepen our understanding of this condition using the most accurate and reliable of available methods. A precise characterization of its relationship with motor abnormalities will enable identification of initial symptoms and earlier detection of dementia, potentially providing sufficient time to intervene and halt its progress.

Research question

With this goal in mind, this review complements previous reviews [10, 11] by systematically assessing the quality of existing research and answering whether the impact of attention impairment on motor function – operationalized as dual-task cost - is higher in more cognitively impaired adults?

Methods

To identify relevant evidence, the author searched PubMed in September and October of 2017 using the following queries: "motor AND dual task AND dementia," "Motor behavior AND dual task AND dementia."

To be included in this review, studies needed to: 1) be peer-reviewed and published in English between January 1970 and October 2017, 2) use validated measures (e.g., the Mini-Mental State Examination [12] or the Montreal Cognitive Assessment

[13]) neuropsychiatric exam or medical history to identify patients with dementia, 3) include at least two groups of subjects, each group with a different level of cognitive impairment, e.g., healthy controls vs. mild cognitive impairment or mild cognitive impairment vs. Alzheimer's disease, 4) provide a quantitative, objective measurement of motor function during a dual-task test. Furthermore, the author excluded studies on participants with conditions that could influence motor performance, e.g., traumatic brain injury or dyspraxia. Relevant studies cited in articles meeting eligibility criteria were added to the set of reviewed papers. Literature reviews, expert opinions, and commentaries were excluded from this review.

Data Collection

Abstracts of all retrieved publications were assessed for relevance. The resultant subset of studies was reviewed to determine if inclusion criteria were met. The author abstracted data published in those papers that met this requirement using a standardized form. The abstracted information included: study type (cross-sectional or longitudinal), how cognitive function was assessed, sample characteristics (size, inclusion and exclusion criteria, mean age, comorbidities), characteristics of comparison groups (e.g., how cognitive impairment was defined, type and severity of dementia, size, mean age), details of tests used (single-task, dual-task and how they were implemented), reported measures of motor function, and statistical findings relevant to the objective of this review.

Definitions of difference and change in motor function

For the purpose of this review, I define a difference in motor function as a statistically significant difference ($p \leq 0.05$) in at least one parameter of motor function between two groups of subjects (between-group design). In turn, a change in motor function parameters is a statistically significant difference ($p \leq 0.05$) in at least one parameter between the single and dual performance measurements of the same group of subjects (within-subject design).

Quality Assessment

To assess the quality of each study, the author used Downs and Black criteria [14]. Following previous research [15, 16], the scale was adapted to better match the nature of reviewed studies. In particular, I removed nine items regarding follow-ups, adverse effects, blinding, compliance, and randomization of group assignment. Furthermore, based on established practice [17], the author modified the question about statistical power. The revised version evaluates whether reviewed studies presented a power calculation including determining sample size necessary to detect relevant effect sizes (Yes/No). This revised instrument provides a score from 0 to 19 points based on 18 items (Appendix A) with higher values corresponding to studies of higher quality.

Results

Study Selection

The initial literature search returned 221 articles. After removing 13 duplicates, 208 abstracts were reviewed for eligibility, of which 190 were subsequently

excluded. The resulting set of 18 articles was reviewed fully. Additionally, the author identified six more relevant articles in the bibliographies of studies under review. These articles also underwent full examination. In total, 24 articles were fully reviewed; the author excluded 12 of them. Consequently, this systematic review is based on the remaining 12 studies (Figure 1).

Study characteristics

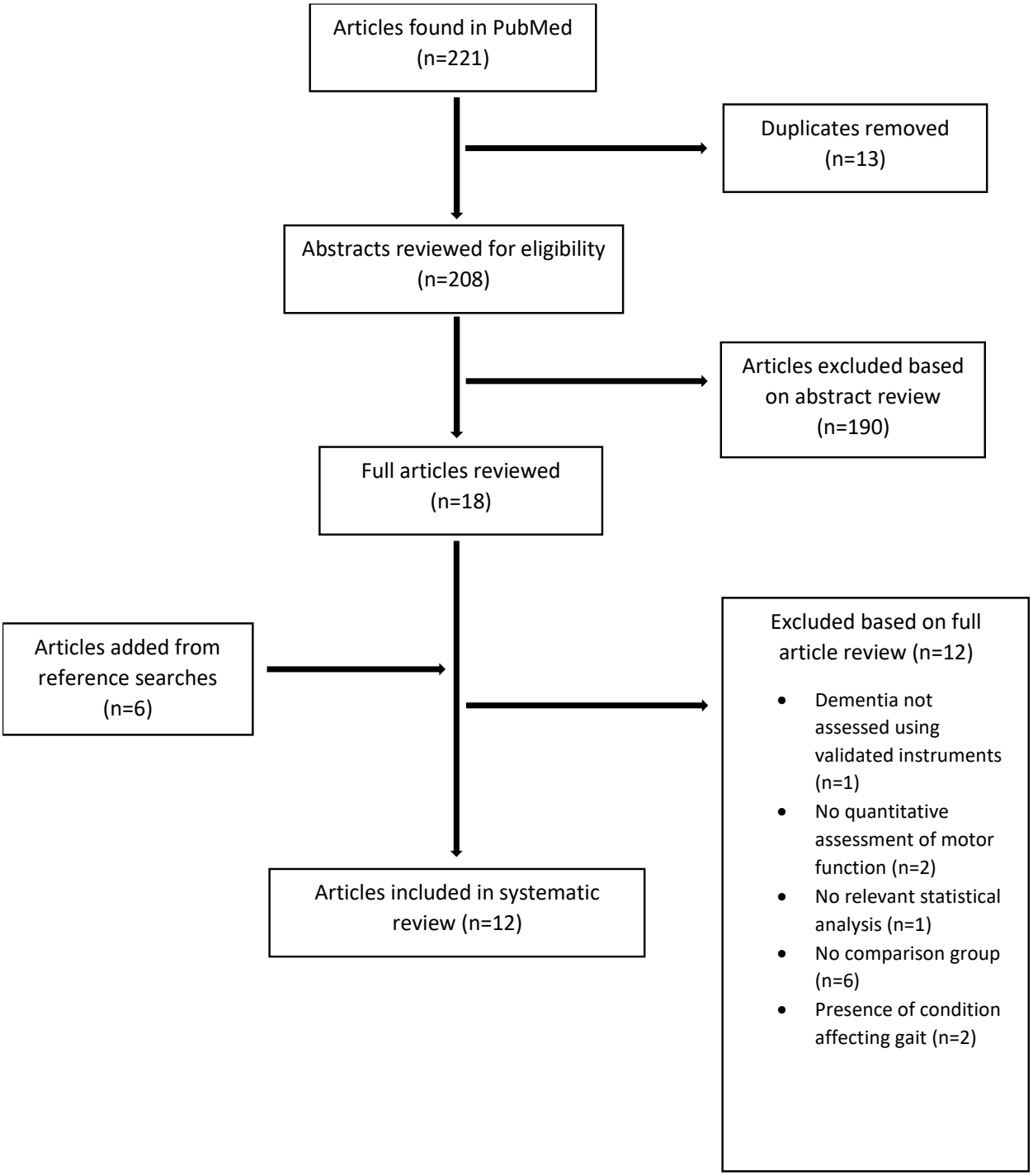
Design

Of reviewed studies, nine[18-26] focused solely on walking tasks. One study[27] focused on only the "Timed Up and Go" task (TUG). Two studies[28, 29] included both TUG and walking tasks (Table 1).

All included studies were lab experiments with two to four comparison groups (μ=2.75, σ=0.62, median=3, mode=3). Mean group size was 23 (σ=15, max=50, min=6).

With one exception[26], all studies included a control group of healthy controls; however, one study [30] did not use this group in its statistical analysis. Seven studies[19, 20, 22, 24, 27-29] included patients with Alzheimer's disease (AD). Nine studies [20-25, 27-29] investigated patients with mild cognitive impairment (MCI). Two of these articles[21, 25] focused on amnestic MCI (aMCI) (Table 2).

Figure 1. Flow diagram of selection process.



1. Table of evidence

Author, year	*Participants*[1]	*Conditions affecting motor function excluded?*	*Was depression an exclusion criterion?*	*Study groups characteristics*	*Relevant motor function tests*	*Difference in motor function*[2]	*Change in motor function (dual-task cost)*[2]	*Difference in dual-task cost between groups*[2]
Borges et al., 2015	n = 104 Older adults between 60 and 88 years old Exclusion criteria: - neurological conditions other than mild to moderate dementia, - conditions that could influence cognitive function.	Yes	No	Healthy (n=36, age=72.6±5.4, MMSE=28.6±1.4) MCI (n=42, age=75.5±5.3, MMSE=27.4±2.1) AD (n=26, age=74.3±5.6, MMSE=22.6±3.0)	TUG	Time (Healthy<MCI<AD)	NA[3]	NA
					TUG + cognitive task (verbal fluency)	Time (Healthy<MCI<AD)	Time↑ (compared to TUG)	NR[4]
					TUG + manual task (carrying a full cup of water)	Time (Healthy<MCI<AD)	Time↑ (compared to TUG)	NR
					TUG + cognitive + manual tasks	Time (Healthy<MCI<AD)	Time↑ (compared to TUG)	NR
Bruce-Keller et al., 2012	n = 100 Elderly subjects without severe depression	No	Yes	Healthy (n=50, age=74.2±7.8, MMSE=28.7±1.6, classified as having neurocognitive status considered normal for age using Uniform Data Set Neuropsychological Battery) Dementia (n=50, age=74.2±8.1, MMSE=20.6±6.4, CDR=0.5-1.0 for 46/50 subjects and CDR=2.0 for 4 subjects)	Walking	Cadence (Dementia<Healthy) Right stride length (Dementia<Healthy) Speed (Dementia<Healthy)	NA	NA
					Walking + cognitive distraction (verbally spelling common five-letter words backwards)	Cadence (Dementia<Healthy) Right stride length (Dementia<Healthy) Speed (Dementia<Healthy)	NR	NR
Camicioli et al., 1997	n = 41 Older adults Exclusion criteria: - major health conditions, - no hypertension, - no cerebrovascular diseases or PD.	No	No	Healthy young old (yOld) (n=13, age=72±3.6, MMSE=29±1, CDR=0) Healthy old old (oOld) (n=11, age=86±4.3, MMSE=28±1.1, CDR=0) AD (n=7, age=74±13, MMSE=21±4.3, CDR=1)	Walking	Steps (AD, oOLD>yOLD), Speed (AD, oOLD>yOLD)	NA	NA
					Walking + talking (male and female name recitation)	NR	NR	Speed cost (AD>oOLD, yOLD)
Gillain et al., 2009	n = 34 Older adults with MCI and AD Healthy controls: age > 65 Exclusion criteria: - vascular stroke with sensory or motor sequelae, - PD, - non-compensated issues with blood pressure, - inability to walk without assistance, falls or hospitalization in the last 6 months.	Yes	No	Healthy (n=14, age = 72.53, MMSE = 28.21±1.58, CDR = 0) MCI (n=14, age = 72.85, man MMSE = 26.71±1.68, CDR < 0.5) AD (n=6, age = 73.66, MMSE = 22.83±2.14, CDR ≥1)	One leg balancing	Body movements per second (AD>Healthy)	NA	NA
					One leg balancing + counting down from 50		NR	NR
					TUG	Time (AD>Healthy) Number of steps (AD>Healthy)	NA	NA
					TUG + counting down from 50	Time (AD>Healthy, MCI) Number of stops (AD>Healthy, MCI) Number of steps (AD>Healthy, MCI)	NR	NR
					30-meter walk	Speed (AD<Healthy) Stride frequency (MCI<Healthy) Stride length (AD<Healthy) Regularity (AD<MCI)	NA	NA
					30-meter walk + counting down from 50	Speed (AD<MCI<Healthy)	Speed (all groups↓)	

						Frequency (MCI<Healthy) Stride length (AD<Healthy) Regularity (AD<MCI, Healthy)	Frequency (all groups↓) Stride length (MCI↓, AD↓) Symmetry (Healthy↑) Regularity (MCI↓, AD↓)	Symmetry cost (Healthy<AD, MCI)
Maquet et al., 2010	n = 34 Older adults (65 years or older) living at home Exclusion criteria: - history of falls or being in a hospital within the last 6 months, - mental retardation, neurological conditions including brain injury and epilepsy, - history of substance abuse, - major systemic conditions, - taking medication affecting brain function.	Yes	Yes	Healthy (n=14, age=74±5, CDR=0) MCI (n=14, age=73±4, CDR=0.5, MMSE ≥24) AD (n=6, age=74±4, CDR=1, MMSE ≥20)	Walking at comfortable speed Walking at comfortable speed + simultaneous backward counting	Stride frequency (MCI<Healthy) Speed (AD<MCI<Healthy) Step symmetry (MCI, AD<Healthy) Step frequency (MCI<Healthy)	NA Speed (Healthy↓ MCI↓) Stride frequency (all groups) Stride length (MCI↓) Step symmetry (MCI↓)	NA NR
Montero-Odasso et al., 2014	n = 99 Older adults (65 years or older) Exclusion criteria: - needing walking aids, - not proficient in English, - PD, - use of psychotropics.	Yes	Yes	Healthy (n=35, age=70.37±3.93, MMSE=29.31±1.02, MoCA=28.06±1.78) Nonamnestic MCI (naMCI) (n=22, age=74.18±6.54, MMSE=29.14±0.83, MoCA=25.67±2.03) Amnestic MCI (aMCI) (n=42, age=77.33±7.26, MMSE=27.24±2.07, MoCA=22.76±2.88) Note: this study does not include any statistical analysis comparing MCI participants to healthy controls	Walking Walking + counting down by one Walking + subtracting serial sevens from 100 Walking + naming animals	Stride time variability (aMCI>naMCI) Speed (aMCI<naMCI) Stride time variability (aMCI>naMCI) Speed (aMCI<naMCI) Speed (aMCI<naMCI)	NA NR NR NR	NA Speed cost (aMCI>naMCI) Speed cost (aMCI>naMCI) Speed cost (aMCI>naMCI)
Muir et al., 2012	n = 74 Older adults (over 65 years old) MCI and AD subjects were recently diagnosed. Exclusion criteria: - needing walking aids, - not understanding English, - history of falls during the last year, - neurological disorders (including PD) with residuals effects, - use of psychotropics.	Yes	Yes	Healthy (n=35, age=71±5.0, MMSE=29.5±0.6, MoCA=28.2±1.5) MCI (n=29, age=73.6±6.2, MMSE=27.5±1.9, MoCA=23.4±2.8, CDR=0.5) AD (n=23, age=77.5±5.0, MMSE=24.2±2.3, MoCA=17.2±3.4)	Walking Walking + naming animals Walking + counting backwards by ones Walking + counting backwards by sevens	Stride time variability (MCI, AD>Healthy) Speed (MCI, AD<Healthy) Stride time variability (MCI, AD>Healthy) Speed (MCI, AD<Healthy) Stride time variability (MCI, AD>Healthy) Speed (MCI, AD<Healthy) Stride time variability (MCI, AD>Healthy)	NA Speed ↓ Stride time variability↑ Stride time variability↑ Speed (MCI↓, AD↓) Stride time variability (all groups)	NA Speed cost (MCI, AD<Healthy) Speed cost (MCI, AD<Healthy)

	Additional exclusion criteria for healthy controls: - presence of memory complains, - poor performance on cognitive tests, - functional impairment.							
Nascimbeni et al., 2015	n = 23 Adults between 65 and 85 years old Exclusion criteria: - use of walking aids, - recent serious illnesses or surgeries, - conditions requiring taking psychiatric medications which could impact cognitive function. Additional exclusion criterion for healthy controls: - presence of functional impairment or cognitive complaints.	Yes	No	Healthy (n=10, age=72±3.87, mean MODA = 93.91±4.49) MCI (n=13, age=76±3.9, mean MODA=84.67±7.4)	Walking Walking + producing words starting with the letters "A", "F" or "S" Walking + recalling a short story Walking + counting backwards	Speed (MCI<Healthy) Double-support time (MCI<Healthy) Speed (MCI<Healthy) Double-support time (MCI<Healthy) Speed (MCI<Healthy) Double-support time (MCI<Healthy) Speed (MCI<Healthy) Double-support time (MCI<Healthy)	NA Speed ↓ Stride time↑ Stride time variation↑ Speed ↓ Stride time↑ Stride time variation↑ Speed ↓ Stride time↑ Stride time variation↑	NA NR NR NR
Pettersson et al., 2005	n = 140 Adults symptomatic of cognitive decline or suspected having dementia	No	No	Healthy (n=33, age=57±9.2, MMSE=29) MCI (n=59, age=60±7.3, MMSE=28) AD (n=22, age=68±9.9, MMSE=24) OD (n=26, age=64±10.5, MMSE=25)	TUG TUG + carrying a glass of water Walking + talking (no more details provided)	Time (AD> Healthy; OD> Healthy, MCI) NR NR	NA NR NR	NA TUG cost [time] (AD> Healthy; OD> Healthy, MCI) Speed cost (AD> Healthy)
Pettersson et al., 2007	n = 37 Healthy adults (45 - 64 years old), some with cognitive impairment Exclusion criterion: - not living at home independently	Yes	No	Healthy (n=25, age=55±4.7, MMSE=29) MCI (n=6, age=59±3.4, MMSE=28.5) AD (n=6, age=58±1.9, MMSE=22.5)	Walking Walking + talking (male or female name recitation)	Speed (AD<Healthy) Speed (AD<Healthy)	NA NR	NA Speed cost (AD>Healthy)
Tseng et al., 2014	n = 26 Older adults with no cognitive impairments other than amnestic mild cognitive impairment (aMCI). Exclusion criteria: - cerebrovascular disease, - dementia or non-amnestic MCI,	Yes	No	Healthy (n=10, age=61.8±6.5, MMSE=28.9±1.0, Wechsler Memory Scale-Revised Logical Memory: 1) Logical Memory (immediate) 15.6±4.8, 2) Logical Memory (delayed) 13.6±4.5) amnestic MCI (aMCI) (n=16, age=64.4±5.3, MMSE=28.8±1.5, Clinical Dementia Rating (CDR) score of 0.5 (memory	Walking as fast as possible for 10 meters Walking as fast as possible for 10 meters + generating as many words starting with “c” as possible Walking as fast as possible for 10 meters + reciting backwards previously	No difference Speed (aMCI<Healthy) Speed (aMCI<Healthy)	NA NR NR	NA Speed cost (aMCI>Healthy) Speed cost (aMCI>Healthy)

	- state-dependent psychological or neurological disorder, - diabetes mellitus, - uncontrolled high blood pressure, - cardiovascular condition, - taking medications that could impact cognitive or motor function.			box score ≥0.5), Wechsler Memory Scale-Revised Logical Memory: 1) Logical Memory (immediate) 11.8±2.6, 2) Logical Memory (delayed) 9.8±2.2)	memorized 5-number digit string Walking as fast as possible for 10 meters + continuously serially subtracting 7 (e.g., 100 -7=93, 93 – 7=86, etc.) Walking as fast as possible for 10 meters + recall three words (door, nickel, bus), sort them alphabetically, and recite them immediately after being instructed to walk	Speed (aMCI<Healthy) Speed (aMCI<Healthy)	NR NR	Speed cost (aMCI>Healthy) Speed cost (aMCI>Healthy)
Wittwer et al., 2014	n = 29 Older adults (age over 65 years) Exclusion criteria: - needing walking aids to walk over 100 meters, - uncorrected visual disorders.	Yes	No	Mild dementia (n=19, age=80.5±5.9, MMSE=23.6±1.9) Moderate - severe dementia (n=11, age=79.7±5.9, MMSE=15.4±4.5)	Walking at comfortable speed Walking at comfortable speed + carrying a tray with two empty glasses	NR NR	NR for experimental groups (only reported for the whole cohort)	No significant results for any of the following reported measures: velocity, cadence, stride length, stride time, stride width, stride length variability, stride time variability.

Note:

[1] Only key exclusion criteria listed;

[2] Only significant results of quantitative measurements are reported ($p \leq 0.05$);

[3] NA – not applicable;

[4] NR – not reported;

Table 2. Experimental groups

Author	*Condition*									
	Healthy controls	AD	MCI	aMCI	naMCI	Dementia	Moderate to severe dementia	Mild dementia	Other dementia
Borges et al., 2015	✓	✓	✓						
Bruce-Keller et al., 2012	✓					✓			
Camicioli et al., 1997	✓	✓							
Gillain et al., 2009	✓	✓	✓						
Maquet et al., 2010	✓	✓	✓						
Montero-Odasso et al., 2014	✓		✓	✓	✓				
Muir et al., 2012	✓	✓	✓						
Nascimbeni et al., 2015	✓		✓						
Pettersson et al., 2007	✓	✓	✓						
Pettersson et al., 2005	✓	✓	✓						✓
Tseng et al., 2014	✓		✓	✓					
Wittwer et al., 2014							✓	✓	
Sum	11	7	9	2	1	1	1	1	1
%	91.67%	58.33 %	75.00 %	16.67 %	8.33%	8.33%	8.33%	8.33%	8.33%

Assessment of cognitive function

All studies except one [23] used MMSE as a criterion for group assignment. Five studies used CDR [18-20, 25, 29], two used MoCA [21, 22], and one used MODA [23].

Participant characteristics

Most participants were older adults. Mean sample ages ranged from 55±4.7 [24] to 80.5±5.9 [26]. None of the studies provided information about participants' socio-economic status. Only one study included information about ethnicity [19].

Quality assessment

Quality of included studies was assessed using modified Downs and Black criteria[14]. Scores ranged from eight to 12 (42% to 63%) out of 19 with a mean of 10.58 and a standard deviation of 1.24 (55.7% and 7%, respectively). None of the studies presented calculations of power to determine the appropriate sample size and demonstrated that participants were representative of the entire population.

Motor function

Reported parameters

Overall, 16 different gait parameters were reported. All 11 relevant studies reported gait speed[18-26, 28, 29], four reported stride time variability [21-23, 26], and three stride length [20, 26, 29]. Eight parameters were reported only once (Table 3). On average, studies that scored over 50% on quality assessment reported fewer gait parameters than those that scored 50% or lower (2.67 vs. 6, respectively).

Dual-task differences (between-groups)

GAIT

Eight [18, 20-25, 29] out of 11 relevant studies [18-26, 28, 29] reported between-groups differences in gait speed during dual-task tests. Two [21, 22] out of four studies [21-23, 26] reported similar differences in stride time variability (Table 3).

TUG

Two [27, 29] out of three TUG papers [27-29] reported differences in dual-task tests. Both studies reported differences in time; one [29] reported differences in numbers of stops and steps (Table 2).

Table 3. Gait parameters in dual-task tests

Author, year	*Speed*	*Stride time variability*	*Stride length*	*Cadence*	*Step symmetry*	*Stops*	*Stride frequency*	*Stride time*	*Double support time*	*Right stride length*	*Step regularity*	*Step frequency*	*Step number*	*Stride length variability*	*Stride regularity*	*Stride width*
Bruce-Keller et al., 2012	✓ D			✓ D						✓ D						
*Camicioli et al., 1997**	✓DTCd											✓	✓			
Gillain et al., 2009	✓ D, DTC		✓ D, DTC		✓ DTC, DTCd	✓	✓ D, DTC				✓ D, DTC					
Maquet et al., 2010	✓ D, DTC		✓ DTC		✓ D, DTC	✓	✓ D, DTC								✓	
Montero-Odasso et al., 2014	✓ D, DTCd	✓ D														
Muir et al., 2012	✓ D, DTC, DTCd	✓ D, DTC														
Nascimbeni et al., 2015	✓ D, DTC	✓ DTC						✓ DTC	✓ D							
Pettersson, 2005	✓ DTCd															
Pettersson et al., 2007	✓ D, DTCd															
Tseng et al., 2014	✓ D, DTCd															
Wittwer et al., 2014	✓	✓	✓	✓				✓						✓		✓

D - significant difference between groups performing a dual-task involving this parameter ($p \leq 0.05$)
DTC - significant change in this parameter between single and dual-task ($p \leq 0.05$)
DTCd – significant difference in dual-task cost between groups ($p \leq 0.05$)
Differences between groups are reported when there was statistically significant difference between at least two groups of subjects.

Dual-task cost difference

GAIT

Among 11 studies characterizing gait [18-26, 28, 29], eight reported differences in dual-task costs [19, 21, 22, 24-26, 28, 29] and seven reported them to be statistically significant [19, 21, 24, 25, 28-30]. In six [19, 21, 24, 25, 28, 29] out of the seven studies [19, 21, 24-26, 28, 29] these results concerned gait speed; in the remaining one [29], the difference regarded step symmetry.

Only one [21] of the seven studies [19, 21, 24-26, 28, 29] reported a significant difference between groups of patients with varying levels of cognitive impairment. The remaining six studies [19, 24-26, 28, 29] found differences between healthy controls and patients with cognitive impairment but were unable to differentiate between cognitively impaired patients (Table 1).

TUG

Among the three studies measuring TUG [27-29], only one reported differences in dual-task costs [28]; this difference was statistically significant.

Discussion

Summary of findings

Reviewed studies provide robust evidence for the difference in gait speed between healthy participants and individuals with cognitive impairment (MCI and AD) during dual-task tests. Furthermore, the author found compelling evidence for the difference in dual-task cost for gait speed between those groups of participants. However, existing findings suggest such a difference does not exist between patients

with MCI and AD. There is insufficient evidence to make any meaningful conclusions about other gait parameters and performance on the TUG test.

The first finding confirms the conclusions of other reviews[10, 11, 31]. The remaining results, especially those regarding dual-task costs and quality assessments, constitute novel contributions of this review.

Methodological issues

Reviewed studies reported 16 different gait parameters in total, of which only gait speed was reported by all authors (Table 3). While the exploration of relationships between cognitive impairment and novel motor function parameters can lead to important discoveries, it is essential that a set of common motor metrics and statistical comparisons (e.g., within-group dual-task cost and between-groups differences in dual-task cost) is consistently reported in all articles. Such harmonization would enable easier comparison of results across studies as well as facilitate evaluation, generalization, and translation of findings.

To ensure that results are generalizable it is crucial to demonstrate representativeness of participants and recruitment facilities. Unfortunately, none of the reviewed studies showed that recruited subject pools share characteristics with the older adult population. Given a high prevalence of depression among AD patients[32], the exclusion of depressed patients from some of the reviewed studies (Table 1) suggests that generalizability of findings may be limited. Furthermore, none of the reviewed articles reported information about the participants' socioeconomic status (SES). In the light of very strong evidence for the impact of

SES on health outcomes [33, 34] stemming from, e.g., economic (e.g., limited access to healthcare) or biological (e.g., brain's different levels of exposure to stress over lifetime[35]) reasons, it is crucial that researchers report, if not control for, SES.

Finally, none of the studies presented evidence that sample sizes were determined using power calculations. Consequently, interpretation of reported findings, especially involving samples of 6 or 7 participants (Table 1), are challenging, even if such studies were otherwise well-designed.

Clinical implications

Results of this review suggest that simple dual-task motor function tests (e.g., walking and talking) might augment traditional screening tests for cognitive impairment[36], especially if conducted regularly. Furthermore, given the pervasiveness of falls in patients with dementia[37], clinical practitioners should consider regularly screening patients at an elevated risk of fall complications (e.g., older adults with osteopenia, osteoporosis or coagulation disorders) for changes in both cognitive decline and motor function.

Research implications and Future work

The primary focus of reviewed studies was on improving our understanding of the interplay of cognition and motor function. Currently, the dominating approach in this strain of research is testing if - and under what conditions - motor function of groups of individuals with varying levels of cognitive impairment differ from one another. However, existing strong evidence for the presence of such group differences does not guarantee clinical efficacy of motor function testing in detecting

dementia. Established data-driven techniques (e.g., classification trees, random forests) and computational models[38] could enhance traditional statistical approaches by allowing to evaluate the diagnostic performance of such tests using longitudinal idiographic data.

The advent of wearable monitoring devices and other unobtrusive remote sensors[39] allows for continuous collection of temporary dense human motor data possibly enabling early detection of dementia[38]. However, all studies included in this review took place in laboratory settings. New research conducted *in situ* using data from unobtrusive sensors is needed to assess the ecological validity of existing findings and aid patients at risk of cognitive impairment.

Conclusions

Healthy and cognitively impaired individuals differ in gait speed and changes in gait speed when performing dual-task tests. However, existing evidence suggests no differences in dual-task cost between patients with MCI and AD. Harmonization of reported motor parameters and comparative statistical tests as well as ensuring that recruited samples are representative and of sufficient size will strengthen the quality of evidence. Applying modern analytical approaches to idiographic, ecologically valid data will improve the clinical relevance of research in this area.

References

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Appendix A. Quality assessment form

1. Is the hypothesis/aim/objective of the study clearly described?	**Yes = 1;** **No = 0**
2. Are the main outcomes to be measured clearly described in the introduction or methods section? If the main outcomes are first mentioned in the Results section, the question should be answered no.	**Yes = 1;** **No = 0**
3. Are the characteristics of the patients included in the study clearly described? In cohort studies and trials, inclusion and/or exclusion criteria should be reported. In case-control studies, a case-definition and the source for controls should be provided.	**Yes = 1;** **No = 0**
4. Are the interventions of interest clearly described? Treatments and placebo (where relevant) that are to be compared should be clearly described.	**Yes = 1;** **No = 0**
5. Are the distributions of principal confounders in each group of patients to be compared clearly described? A list of principal confounders is provided.	**Yes = 2;** **Partially = 1;** **No = 0**
6. Are the main findings of the study clearly described? Simple outcome data (including denominators and numerators) should be reported for all major findings so that the reader can check the major analyses and conclusions. (This question does not cover statistical tests that are considered below).	**Yes = 1;** **No = 0**
7. Does the study provide estimates of the random variability in the data for the main outcomes? In non-normally distributed data, the inter-quartile range of results should be reported. In normally distributed data, the standard error, standard deviation, or confidence intervals should be reported. If the distribution of the data is not described, it must be assumed that the estimates used were appropriate and the question should be answered yes.	**Yes = 1;** **No = 0**
8. Have actual probability values been reported (e.g., 0.035 rather than <0.05) for the main outcomes, except where the probability value is <0.001? If no p values are presented, the question should be answered 'no'. If *p* values presented and there is a mixture of reporting (some presented as < or > specific figures, some as equality, e.g. $p = 0.034$), question should be answered 'yes'.	**Yes = 1;** **No = 0**

9. Were the subjects asked to participate in the study representative of the entire population from which they were recruited? The study must identify the source population for patients and describe how the patients were selected. Patients would be representative if they comprised the entire source population, an unselected sample of consecutive patients, or a random sample. Random sampling is only feasible where a list of all members of the relevant population exists. Where a study does not report the proportion of the source population from which the patients are derived, the question should be answered as unable to determine.	**Yes = 1;** **No = 0;** **Unable to determine = 0**
10. Were those subjects who were prepared to participate representative of the entire population from which they were recruited? The proportion of those asked and agreed to participate should be stated. Validation that the sample was representative would include demonstrating that the distribution of the main confounding factors was the same in the study sample and the source population.	**Yes = 1;** **No = 0;** **Unable to determine = 0**
11. Were the staff, places, and facilities where the patients were treated **representative of the treatment the majority of patients receive?** For the question to be answered 'yes' the study should demonstrate that the intervention was representative of that in use in the source population. The question should be answered no if, for example, the intervention was undertaken in a specialist center unrepresentative of the hospitals most of the source population would attend.	**Yes = 1;** **No = 0;** **Unable to determine = 0**
12. If any of the results of the study were based on "data dredging," was this made clear? Any analyses that had not been planned at the outset of the study should be clearly indicated. If no retrospective unplanned subgroup analyses were reported, then answer 'yes'.	**Yes = 1;** **No = 0;** **Unable to determine = 0**
13. Were the statistical tests used to assess the main outcomes appropriate? The statistical techniques used must be appropriate to the data. For example, nonparametric methods should be used for small sample sizes. Where little statistical analysis has been undertaken but where there is no evidence of bias, the question should be answered yes. If the distribution of the data (normal or not) is not described it must be assumed that the estimates used were appropriate and the question should be answered 'yes'.	**Yes = 1;** **No = 0;** **Unable to determine = 0**

14. Were the main outcome measures used accurate (valid and reliable)? For studies where the outcome measures are clearly described, the question should be answered yes. For studies that refer to other work or demonstrates the outcome measures are accurate, the question should be answered as yes.	**Yes = 1;** **No = 0;** **Unable to determine = 0**
15. Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population? For example, patients for all comparison groups should be selected from the same hospital. The question should be answered "unable to determine" for cohort and case control studies where there is no information concerning the source of patients included in the study.	**Yes = 1;** **No = 0;** **Unable to determine = 0**
16. Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time? For a study which does not specify the time period over which patients were recruited, the question should be answered as "unable to determine."	**Yes = 1;** **No = 0;** **Unable to determine = 0**
17. Was there adequate adjustment for confounding in the analyses from which the main findings were drawn? This question should be answered no for trials if: the main conclusions of the study were based on analyses of treatment rather than intention to treat; the distribution of known confounders in the different treatment groups was not described; or the distribution of known confounders differed between the treatment groups but was not taken into account in the analyses. In nonrandomized studies, if the effect of the main confounders was not investigated or confounding was demonstrated but no adjustment was made in the final analyses, the question should be answered as "no".	**Yes = 1;** **No = 0;** **Unable to determine = 0**
18. Did the authors present a power calculation including determining sample size necessary to detect relevant effect sizes?	**Yes = 1;** **No = 0;** **Unable to determine = 0**

Adaptation of: Downs SH, Black N., The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Health. 1998;52(6):377-84.